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Original scientific paper

ESTIMATION OF GROWTH CURVE PARAMETERS IN MEHRABAN SHEEP USING DIFFERENT NON-LINEAR MODELS

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Latifi M. and M. Bohlouli (2020). *Estimation of growth curve parameters in Mehraban sheep using different non-linear*.-.Genetika, Vol 52, No.2, 815-823.
The aim of this study was to compare non-linear models to determine which model describes the growth pattern best for daily weight records of Mehraban sheep. The Non-linear Negative exponential, Brody, Gompertz, Logistic, and von Bertalanffy models were applied. The data was collected between 2001 and 2010 from Mehraban breeding unit of the Agriculture Organization of Hamadan province in western Iran that were included 8299 daily weight records from 2206 animals from birth to 409 days of age. The NLIN procedure in SAS software was used to evaluate changes in body weight among different weighing age. The best model was determined by Adjusted Coefficient of Determination (R^2_{adj}), Root Mean Square Error (*RMSE*) criteria, Akaike's information criteria (AIC) and Bayesian information criteria (BIC). For all models, R^2_{adj} were mostly higher than 93%. Based on used criteria, the Brody model was selected as the best Model to explain the biological growth of Mehraban sheep. The results revealed that the Brody model can be practically useful for setting management strategies such as determining nutritional programs and the appropriate age for slaughter of Mehraban sheep.
Keywords: adult weight, Brody model, growth trait, model comparison

INTRODUCTION

Growth traits are one of the economically important traits in the sheep industry. In Iran, the lamb sale is the main source of income for sheep breeder, while other products are in secondary importance (AGHAALI GAMASAEE *et al.,* 2010 and BOHLOULI *et al.,* 2013). Mehraban sheep, as a large-sized breed, is one of the local breeds of Iran and dispread mainly in the west of the country, Hamadan province. There are almost one million heads of Mehraban sheep in Hamadan province. This breed is a fat-tailed sheep, and is adapted to cold and highland environments conditions and primarily used for meat production.

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Growth rate is one of the most important traits, which is associated with the profitability of farm (ABEGAZ *et al.,* 2010). Growth studies in many branches of animal science have demonstrated that more complex non-linear functions are justified and required if the range of the independent variable includes different stages of growth (FEKEDULEGN *et al.,* 1999). The use of growth models is one of the ways that predicted and measured animal's performance such as weight gain. In fact, growth models are linear or nonlinear regression functions that can predict growth at different ages of animal life. Non-linear mathematical functions, empirically developed by depicting body weight against age, have been appropriate to characterize the growth curve in different animal classes (MALHADOA *et al*., 2009). An investigation of animal growth patterns allows development to be monitored, which can help to determine the optimum slaughter time (DA SILVA *et al.,* 2012). Therefore, the objective of this study was to describe the growth curve of Mehraban sheep using the Negative exponential, Brody, Gompertz, Logistic and von Bertalanffy models.

MATERIAL AND METHODS

The weight records used in this study was collected at Mehraban sheep breeding unit of the Agriculture Organization of Hamadan province in western Iran, between 2001 and 2010. The dataset was included 8298 daily weight records from 2126 animals from birth to 409 days of age. Number of records and average weights for different ages are shown in Fig. 1.

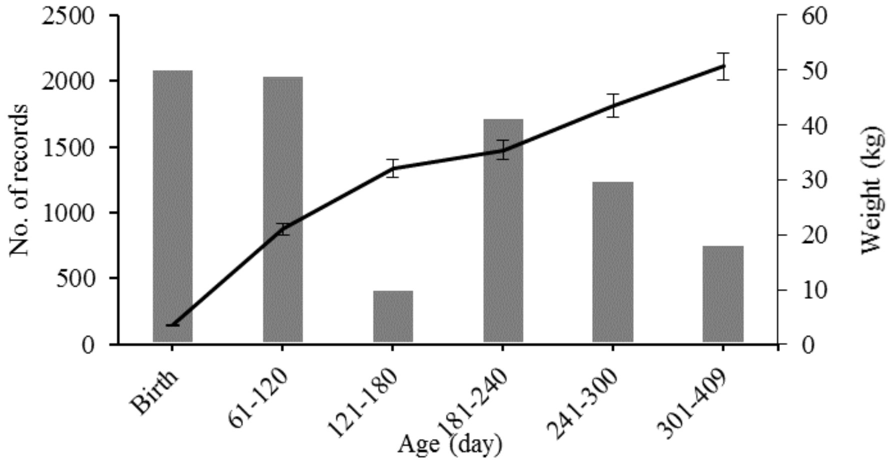

Fig. 1. Number of records and mean weights among age intervals.

Ewes were first exposed to rams at approximately 18 months old. Mating season was from September to October, with February to April lambing. At birth, lambs were identified; and date of birth, sex and type of birth were recorded. The suckling stage lasts approximately for 3 months. Flocks were grazed during the daytime and housed at night. Also, lambs were kept indoors and fed manually during winter with hay grass. Data were checked, so defective and out of range records were deleted. Finally, each lamb had at least four records for analysis. SAS software (SAS, 2001) was used to evaluate changes in body weight via the NLIN procedure. Five non-linear growth functions were used to evaluate the growth curves of Mehraban sheep. Non-linear growth functions were Negative exponential, Brody, Gompertz, Logistic, and von Bertalanffy; and were fitted to the data in order to model the relationship between weight and age (Table 1).

Table 1. Functions used to describe the growth curve of Mehraban sheep.*

Negative exponential	$y = A[1-\exp^{(-kt)}]$	(BROWN *et al*., 1976)
Brody	$y = A[1-B\ \exp^{(-kt)}]$	(BRODY, 1945)
Gompertz	$y = A\ \exp[-B\ \exp^{(-kt)}]$	(LAIRD, 1965)
Logistic	$y = A/[1 + B\ \exp^{(-kt)}]$	(NELDER, 1961)
Von Bertalanffy	$y = A[1 - B\ \exp^{(-kt)}]^3$	(VON BERTALANFFY, 1957)

* *y* is observed weight at age *t* (day); *A* is asymptotic weight, which is interpreted as mature weight; *B* is an integration constant related to initial animal weight, which is defined by the initial values for *y* and *t*; *k* is maturation rate, which is interpreted as the ratio of maximum growth rate to mature weight.

The models were tested for goodness of fit using adjusted coefficient of determination (R^2_{adj}) that calculated as $1 - \frac{(1-R^2)(N-1)}{n-p-1}$, where R^2, n and p are the multiple coefficient of determination, the number of observations and the number of parameters in the equation, respectively. Root Mean Square Error (*RMSE*) was calculated as $RMSE = \frac{RSS}{\sqrt{n-p-1}}$, where, RSS is residual sum of squares, n is the number of observations and p is the number of parameters in the equation. In addition, two model selection criteria, Akaike's information criteria (AIC) and Bayesian information criteria (BIC) were calculated using the following formulas:

$$AIC = n \times \ln(RSS) + 2p$$

$$BIC = n \times \ln(\frac{RSS}{n}) + p \times \ln(n)$$

According to previous studies (GBANGBOCHE *et al.*, 2008 and LATIFI *et al.*, 2020), the best model was determined by the higher R^2_{adj} and the lowest RMSE, AIC and BIC values.

RESULTS

Estimated parameters using non-linear growth models, correlation coefficient between *A*, *B* and *k*, R^2_{adj} and RMSE for Mehraban sheep are presented in Table 2. Also, predicted body weights (Kg) as a function of age (day) by different growth models for all lambs shown in Figure 2. For all models, R^2_{adj} was mostly higher than 93%. Based on the R^2_{adj} estimate the Brody model provided the highest value for all lambs, male and female; but the Negative exponential model for all lambs and female and the logistic model for male provided the lowest values (Table 2). In addition, the Brody and Logistic models had the lowest and the highest values of RMSE, AIC and BIC for all lambs, male and female, respectively.

Table 2. Estimates of parameters (A, B and k), correlation coefficient between parameters, Adjusted Determination Coefficient (R^2_{adj}) and Root Mean Square Error (RMSE) for the different growth curve in Mehraban sheep

Models	Parameter						R^2_{adj}	RMSE	AIC	BIC
	A ± SE	B ± SE	k ± SE	r_{AB}	r_{Ak}	r_{Bk}				
All lambs										
Negative exponential	63.68 ± 0.44	-	4.21 ± 0.05	-	-0.97	-	93.70	4.23	98438.35	23573.16
Brody	70.21 ± 0.63	0.95 ± 0.00	3.34 ± 0.05	0.005	-0.98	0.11	94.68	3.80	97043.47	22185.30
Gompertz	52.32 ± 0.20	2.46 ± 0.02	9.83 ± 0.08	-0.27	-0.84	0.66	94.29	3.93	97631.05	22772.88
Logistic	48.79 ± 0.15	7.28 ± 0.09	16.00 ± 0.13	-0.19	-0.69	0.77	93.21	4.35	99059.63	24201.46
Von Bertalanffy	55.07 ± 0.24	0.58 ± 0.00	7.66 ± 0.07	-0.25	-0.89	0.57	94.54	3.84	97250.56	22392.39
Male										
Negative exponential	66.52 ± 0.65	-	4.04 ± 0.07	-	-0.98		94.12	4.10	45280.86	11494.03
Brody	73.91± 0.95	0.95± 0.00	3.17 ± 0.07	0.02	-0.98	0.10	95.11	3.74	44533.95	10753.43
Gompertz	54.19 ± 0.28	2.46 ± 0.02	9.58 ± 0.11	-0.27	-0.85	0.66	94.73	3.88	44833.61	11053.08
Logistic	50.40 ± 0.21	7.32 ± 0.13	15.70 ± 0.17	-0.19	-0.69	0.76	93.06	4.21	45580.77	11800.24
Von Bertalanffy	57.14 ± 0.35	0.58 ± 0.00	7.44 ± 0.09	-026	-0.90	0.57	94.98	3.78	44635.40	10854.87
Female										
Negative exponential	60.51 ± 0.56	-	4.44 ± 0.07	-	-0.97	-	93.55	4.06	47198.94	11881.97
Brody	66.11 ± 0.79	0.95 ± 0.00	3.57 ± 0.08	-0.01	-0.97	0.13	94.51	3.75	46518.84	11208.23
Gompertz	50.30 ± 0.26	2.46 ± 0.02	10.02 ± 0.12	-0.26	-0.84	0.66	94.13	3.87	46799.11	11488.49
Logistic	47.06 ± 0.20	7.24 ± 0.13	16.40 ± 0.18	-0.19	-0.69	0.76	93.67	4.25	47509.64	12199.03
Von Bertalanffy	52.80 ± 0.31	0.58 ± 0.00	7.95± 0.10	-0.25	-0.89	0.57	94.39	3.79	46612.58	11301.96

A: asymptotic mature weight; *B*: integration constant; *k*: maturity rate (×10^{-3}); r_{AB}: correlation coefficient between *A* and *B*; r_{Ak}: correlation coefficient between *A* and *k*; r_{BK}: correlation coefficient between *B* and *k*; R^2_{adj}: adjusted determination coefficient; RMSE: root mean square error, AIC: Akaike information criterion; BIC: Bayesian information criterion

The *A* parameter is an estimate of asymptotic weight which can be interpreted as the weight at maturity. For this dataset, the greatest and the lowest values for the parameter *A* were obtained by Brody (for all lambs = 70.21) and logistic model (for all lambs = 48.79), respectively. For all models, the values of *A* for male lambs were higher than those for female lambs. This result indicates that male lambs have higher weight at maturity. For all lambs, the highest (7.28) and lowest (0.58) values of the *B* parameter were estimated using Logistic and Von Bertalanffy models, respectively. For all lambs, the lowest (0.003) and the highest (0.016) estimates of the parameter *k* were for the Brody and logistic models, respectively; and values of *k* were relatively higher for females than that for males.

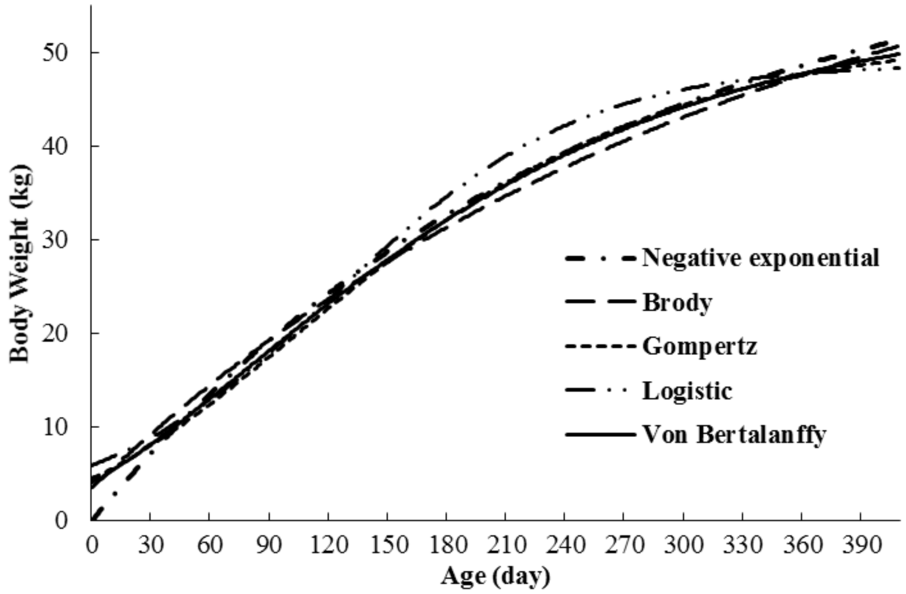

Figure 2. Predicted body weights (kg) as a function of age (day) obtained with different growth models for all lambs of Mehraban sheep

Table 3. contains the predicted versus observed mean weights among different selected ages. In all models, an average body weight predicted at 180 and 270 days of ages was underpredicted and at 400 days of age was overpredicted. The best estimates of average body weights predicted at 120 and 400 days of age were achieved with the Gompertz model.

Table 3. Observed and predicted mean weight values of all lambs of Mehraban sheep from birth to 400 days by using non-linear models

Models	Day							
	0	90	120	180	210	270	300	400
Predicted weight (kg)								
Negative exponential	0.25	19.25	24.27	32.69	36.18	42.05	44.50	50.82
Brody	3.71	19.29	23.67	31.34	34.69	40.54	43.09	50.12
Gompertz	4.56	17.51	22.69	32.15	36.08	42.13	44.34	48.91
Logistic	5.96	17.90	23.60	34.63	38.94	44.48	46.03	48.21
Von Bertalanffy	4.19	18.18	23.20	32.17	35.84	41.83	49.45	49.45
Observed weight (Kg)	3.52	18.92	22.66	35.29	37.76	46.63	44.15	47.00

DISCUSSION

Similar to results of this study, GBANGBOCHE *et al*., (2008) and BAHREINI BEHZADI *et al*., (2014) compared different non-linear functions and selected the Brody model for describing the growth performance of West African Dwarf sheep and Baluchi sheep, respectively. NELDER (1961) mentioned that the Brody model is simplest and easiest function interpretation compared with the other growth curves. TARIQ *et al*. (2013) compared the Gompertz, Logistic, Von Bertalanffy, Richards, Weibull and Morgan-Mercer-Flodin models and indicated that the Morgan-Mercer-Flodin model was the best in Mengali Sheep. In Santa Inês sheep among the Brody, Richards, Von Bertalanffy, Gompertz and Logistic models, the Logistic model was considered as the goodness of fit (DA SILVA *et al*., 2012). Moreover, the Brody model in Hemsin sheep (KOPUZLU *et al.*, 2014) and the Gompertz model in Suffolk sheep (LEWIS *et al*., 2002) were the most appropriate for describing growth function.

MALHADOA *et al.* (2009) mentioned that the parameter *B* represents an integration constant, related to the animal birth weight without a clear biological interpretation. The parameter *k* that defined as maturation rate is another important feature to be considered, since it indicates the growth speed to reach the asymptotic weight (TAYLOR, 1965; HOJJATI and GHAVI HOSSEIN-ZADEH, 2018). Therefore, animals that have higher *k* values will reach puberty sooner (DA SILVA *et al.*, 2012). In this study, relatively higher values of *k* parameter were estimated for females than those for males. In this regard, GHAVI HOSSEIN-ZADEH (2018) presented that females have higher maturity rates.

For parameters *A*, *B* and *k*, respectively the values of 44.99, 0.98 and 0.004 using Shall sheep data (GHAVI HOSSEIN-ZADEH, 2015) and the values of 57.06, 3.59 and 0.004 using Mengali Sheep information, (TARIQ *et al*., 2013). Moreover, using Texel male sheep data, DE FATIMA SIEKLICKI *et al.* (2016) estimated values of 49.47, 0.91 and 0.008 for parameters *A*, *B* and *k*, respectively. In present study based on the best model, the *A*, *B* and *k* values for all lambs were 70.21, 0.95 and 0.003, respectively. These values were similar to the results of BATHAEI and LEROY (1998) in Mehraban sheep, and KOPUZLU *et al*. (2014) using Hemsin sheep data. For a growth curve, the most important biological relationship has been found between *A* and *k* (MCMANUS *et al.,* 2003). As a result of this study, strong negative correlations of -0.98 to -0.69 between *A* and *k* parameters were obtained using different models for all lambs. DA SILVA *et al.* (2012) mentioned that the negative correlation between *A* and *k* parameters implies that the earliest animals are less likely to exhibit high adult weight; i.e., animals that have higher adult weights generally present lower growth rates than animals with a lower adult weight.

As different models were reported as the best model in different studies, it is not easy to give a comprehensive description of growth characteristic by interpreting and relating to the biology of the animal (KOPUZLU *et al.,* 2014). However, according to the characteristics (breed, genetic relationships, recording date, etc.) of the used data, there are evidences that growth modeling has many advantages for domestic animals (SCHINCKEL and DE LANGE, 1996) and can be an important tool for optimizing the management and the efficiency of sheep production.

CONCLUSIONS

In this study, five models including the Negative exponential, Brody, Gompertz, Logistic, and von Bertalanffy models were used to determine the growth pattern in Mehraban sheep. To explain the biological growth of Mehraban sheep based on the lowest values of AIC and BIC, the Brody model was selected as the best model. Accordingly, the Brody model should be considered to set some management strategies such as determining nutritional programs and the appropriate age for slaughter of Mehraban sheep.

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ODREĐIVANJE PARAMATERA KRIVE RASTA KOD MEHRABAN OVACA PRIMENOM RAZLIČITIH NELINEARNIH MODELA

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Izvod

Cilj rada je poređenje nelinearnih modela da se odredi koji model opisuje uzorak rasta bolje za dnevno merenu težinu Mehraban ovaca. Ne-linear negativni eksponencijalni, Brody, Gompertz, Logistic, i von Bertalanffy modeli su primenjeni. Podaci su sakupljani između 2001 i 2010 godine iz Agriculture Organization of Hamadan provinciencije u zapadnom Iranu, inicijalno je uključeno 8299 dnevnih merenja težine od 2206 životinja od rođenja do 409 dana. NLIN procedura u SAS softveru je korišćena da se ispitaju promene u težini između različitih težinskih doba. Najbolji model je određen sa *Adjusted Coefficient of Determination* (R^2_{adj}), *Root Mean Square Error (RMSE)* kriterijumima, Akaike's informacionim kriterijumom (AIC) i Bayesian informacionim kriterijumom (BIC). Za sve modele, R^2_{adj} je bio veći od 93%. Na osnovu korišćenih kriterijuma, Brody model je izabran kao najbolji model da objasni biološki rast Mehraban ovaca. Rezultati dobijeni sa Brody modelom imaju praktičnu primenu za pravljenje strategija menadžmenta kao što su određivanje nutritivnog programa.

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